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# Virtual water highway: water use efficiency in global food trade

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## Abstract

Amid an increasing water scarcity in many parts of the world, virtual water trade as both a policy instrument and practical means to balance the regional, national and global water budget has received much attention in recent years. Built upon the knowledge of virtual water accounting in the literature, this study examines the efficiency of the resource use embodied in the global virtual water trade from the perspectives of exporting and importing countries. Different characteristics between “green” and “blue” virtual water corresponding to rainfed and irrigated agriculture are elaborated. The investigation reveals that the virtual water flows primarily from countries of high water productivity to countries of low water productivity, generating a global saving of water resources. Meanwhile, the domination of green virtual water in the total virtual water trade constitutes low opportunity costs and environmental impacts as opposed to blue virtual water. The results suggest efficiency gains in the global food trade in terms of water resource utilization. The study raises awareness of negative impacts of increasing reliance on irrigation for food production in many countries, including food exporting countries. The findings of the study call for a greater emphasis on rainfed agriculture to improve global food security and environmental sustainability.

## 1. Introduction

With the continuous population growth and related developments, water resources have become increasingly scarce in a growing number of countries and regions in the world. As the largest water user, accounting for over 80% of the global total water withdrawal, food production is directly constrained by water scarcity (Cosgrove and Rijsberman, 2000; Rosegrant et al., 2002). To compensate for the domestic water deficit and meet the food demand, many countries have opted for importing food from abroad. This is virtually equivalent to importing water that would otherwise be needed for producing the food locally. Allan (1993) termed the water embodied in food import

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as “virtual water”. In recent years, the concept of virtual water has been extended to refer to the water that is required for the production of agricultural commodities and industrial goods (Hoekstra and Hung, 2002; Oki et al., 2002). Nevertheless, discussions on virtual water issues have so far focused primarily on food commodities due to their large share in total water use. With the continuous intensification of water scarcity in many areas of the world, the role of virtual water trade in balancing water budget and improving food security is expected to increase (Yang et al., 2003).

Against this background, studies concerning water scarcity, food security and virtual water trade have flourished in recent years. The efforts have greatly helped the understanding of water and food challenges and provided useful information for formulating national and international policies to deal with them. In view of the important role of virtual water trade in alleviating water stress, a number of studies have estimated the scale of virtual water embodied in the global food trade (Hoekstra and Hung, 2002; Oki et al., 2002; Zimmer and Renault, 2002). The results from these studies, however, vary to some extent partly because of the different coverage of food commodities in the calculation. The variations also reflect the complexity of site specific conditions in different regions and countries.

Built upon the virtual water accounting in the literature, this study goes further to examine the efficiency gains embodied in the global virtual water trade with respect to water saving, opportunity costs and environmental impacts. In different countries, the amount of water required for producing a unit of crop differs. A global water saving results when food is exported by countries whose water use is relatively more productive to countries whose water use is less productivity. Flows in an opposite direction lead to an inefficient use of global water resources. Meanwhile, water use in rainfed and irrigated agriculture differs in opportunity costs and environmental impacts. Rainfed agriculture uses the “green water” while irrigated agriculture uses the “blue water”. These characteristics are reflected in the trading of virtual water. As to be elaborated in this study, trading “green virtual water” is more efficient in terms of resources utilization than that of “blue virtual water”, holding other conditions constant.

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Our focus in this study is the global water use efficiency admitting, however, that the virtual water trade issue is more complicated because of the sensitive political and social conditions, which also merit careful analyses. In this study we examine virtual water trade for both importing and exporting countries, estimate the scale of water saving or overuse for different crops resulting from global food trade, and carry out a virtual water partitioning to specify the contribution of green and blue virtual water in global food trade.

Food exporting countries are the source of virtual water. They are imperative players in the global virtual water trade. However, previous studies of virtual water issues have focused overwhelmingly on food importing countries. Little attention has been paid to food exporting countries concerning their water endowments and resource use efficiency, as well as environmental impacts associated with virtual water export. In discussions of the application of the concept, current and future food and water policies of food exporting countries have generally been neglected (Merrett, 2003). With the virtual water trade increasingly being emphasized in the global effort to combat regional water scarcity, the perspective of exporting countries deserves more attention.

The subsequent sections of this paper tackle the following issues: 1) crop virtual water content and water productivity in different countries; 2) the scale of the global water use efficiency, quantified as the water saving, achieved through the global virtual water trade; 3) the economic and environmental implications of green and blue water corresponding, respectively, to rainfed and irrigated agriculture, and; 4) the contribution of green and blue virtual water in the global virtual water trade. Concluding remarks and policy implications are given in the final section.

## 2. Virtual water content and water productivity

In the virtual water literature, a ratio of 1 kg of cereal (excluding rice) to 1 m<sup>3</sup> of water has commonly been used as a rule of thumb in estimating the volume of virtual water imported to or exported from a country. For rice, a ratio of 1 to 2 is often applied (Yang

and Zehnder, 2002; Allan, 2003; Zehnder et al., 2003). This approximation is useful for political and conceptual discussions on virtual water issues. It, however, overlooks the variations in virtual water content among different crops and across countries. In reality, water required for producing a unit product, or virtual water content, varies substantially among different crops and across different climate zones.

Various models have been applied in estimating crop virtual water contents. CROPWAT is one of the mostly used models. The model is developed by the Food and Agricultural Organization of the United Nations (FAO) and is downloadable from the Internet. The climate parameters and crop coefficients required for estimating crop water requirements are available in the FAO databases (FAO, 1986a, 1986b). Steps of the virtual water estimation are given in Fig. 1.

In the CROPWAT model, crop evapotranspiration  $ET_c$  is estimated on the basis of the “reference crop evapotranspiration”  $ET_0$  and the crop coefficient  $K_c$ .

$$ET_c = K_c ET_0 \quad (1)$$

Specific crop water requirement  $CWR_c$  ( $\text{m}^3 \text{ha}^{-1}$ ) over the complete growing period is calculated as:

$$CWR_c = \sum_{i=1}^m ET_{c,i}, \quad (2)$$

where  $m$  is the total number of growing days for crop  $c$ .

Based on the  $CWR_c$ , crop virtual water content ( $CVWC_c$ ,  $\text{m}^3 \text{ton}^{-1}$ ) and its inversion, crop water productivity ( $CWP_c$ ,  $\text{ton m}^{-3}$ ) can be calculated as:

$$CVWC_c = \frac{CWR_c}{Y_c} \quad (3)$$

$$CWP_c = \frac{Y_c}{CWR_c}, \quad (4)$$

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where  $Y_c$  is the yield of crop  $c$  ( $\text{ton ha}^{-1}$ ).

Applying the CROPWAT model, Hoekstra and Hung (2002) estimated the  $CVWC$  for major food crops in different countries. Given the crudeness of the available data and the complexity of crop systems in different countries, errors are inevitable in the estimation. Nevertheless, their study is so far the only systematic estimation of virtual water content of crops on the global scale. Improving the estimation requires more accurate data at the country and sub-country levels, which are not currently available at the global level. For this reason, this study uses the virtual water contents estimated by Hoekstra and Hung (2002). Based on their estimation,  $CWP$  for major food crops in different countries is calculated in this study. The results for selected major crops are displayed in Fig. 2.

Water productivity varies significantly across countries and among crops. Nevertheless, it is noticeable that water productivity for the respective crops is generally high in North America and the Western European countries. Other countries with high water productivity include Argentina, China, Australia, and some countries in the Middle East. In contrast, water productivity is manifestly low in the Sub-Sahara African countries. This situation is expected because water productivity is closely related to the agronomic practices and water management at both regional and farm-level. Efforts to raise water productivity are often associated with greater inputs and improved agronomic practice and water management, which are generally lacking in poor countries.

It should be pointed out that the estimation of crop virtual water contents and crop water productivity are based on the actual crop evapotranspiration. In reality, more water is required in the irrigated production due to the losses during the conveyance and field supply. In most developing countries, for example, the amount of water supplied to irrigated field is typically 2–3 times of that required for actual crop evapotranspiration. At the basin level, although part of the losses on specific irrigation sites can recharge the aquifers or can be used by downstream users and ecosystems, the real losses are nevertheless significant. Recent studies have suggested that the losses to non-beneficial evapotranspiration at the river basin level are between 10–20% of the total

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supply (Seckler et al., 1998). This means that the real water productivity is lower than that estimated above. The discount would be larger in developing countries where the non-beneficial losses are generally greater.

### 3. Virtual water accounting and global virtual water flows

#### 3.1. Virtual water accounting and scale of water saving

A large variety of food commodities is traded in the international market. It is difficult to include all the commodities in the calculation. In this study, the estimation is based on 20 major food crops (items) shown in Table 1. They account for about 70% of the total calorie intake on a world average (FAO, 2003). The rest of the 30% is made up by animal products and other crops, mainly vegetables and fruits. Because not all the traded food commodities are included, the scale of virtual water trade may be underestimated. Nevertheless, this will not significantly affect the major points to be addressed and the conclusions to be drawn. Meanwhile, volumes of virtual water trade estimated in this study may not be compared directly with the results from other studies due to different coverage of crop commodities in the calculation.

The gross volume of virtual water import ( $GVWI$ ) to a country is the sum of crop imports ( $CI_c$ ) multiplied by their associated crop virtual water content ( $CVWC_c$ ) in that country:

$$GVWI = \sum_c (CI_c \times CVWC_c) \quad (5)$$

Similarly, the gross volume of virtual water export ( $GVWE$ ) from a country is the sum of crop exports ( $CE_c$ ) multiplied by their associated crop virtual water content ( $CVWC_c$ ) in that country:

$$GVWE = \sum_c (CE_c \times CVWC_c) \quad (6)$$



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In the global food trade system, the volume of total food export is approximately equal to the volume of total food import to achieve the market clearance. This is especially so when averaged over a period of time as the effect of yearly stock exchange is smoothed out. Concerning the global virtual water trade, however, this equilibrium does not apply. Due to variations in crop virtual water contents, water needed for producing a given amount of food in exporting countries (the production side) can differ from that in importing countries (the consumption side). In other words, the virtual water “value” of a given amount of food is not identical on the two sides. When virtual water imports and exports for all the countries are summed up separately, a gap between the two volumes occurs. Depending on the sign of the gap, water saving or loss in the global food trade can result. Equations for estimating the total global virtual water import ( $TGVWI$ ) and total global virtual water export ( $TGVWE$ ) are expressed as:

$$TGVWI = \sum_{n=1}^N \sum_{c=1}^C GVWI_{n,c} \quad (7)$$

$$TGVWE = \sum_{n=1}^N \sum_{c=1}^C GVWE_{n,c} \quad (8)$$

where  $N$  is the number of countries,  $C$  is the number of crops considered. Water saving/loss generated from the global virtual water trade ( $GNVWT$ ) can be calculated as:

$$GNVWT(N, C) = \sum_{n=1}^N \sum_{c=1}^C (GVWI_{n,c} - GVWE_{n,c}) \quad (9)$$

Table 2 shows the estimates of gross virtual water import and export at the global level. Total volume of virtual water export associated with the food crops considered is about  $644 \text{ km}^3 \text{ year}^{-1}$ . The corresponding volume for import is  $981 \text{ km}^3 \text{ year}^{-1}$ . The difference of  $337 \text{ km}^3 \text{ year}^{-1}$  is the global water saving resulting from the food trade. In

other words, this amount of additional water would otherwise be required if the imported amount of food were produced in the importing countries. Apparently, this water saving is achieved from the generally high water productivity in the food exporting countries in comparison to the food importing countries (Fig. 2).

For individual crops, the scale of water saving varies. For wheat and maize, 41% and 59% of water are saved, respectively. This means that the importing countries would have to use approximately twice as much as the water used in the exporting countries for producing the same amount of wheat and maize they import. The trading of these two crops contributes greatly to the total global water saving. An exception, however, is rice where the volume of virtual water embodied in rice export is larger than that in rice import. This implies that the rice production in the exporting countries requires more water than the production in the importing countries. This may partly be explained by the relatively high crop evapotranspiration in the major rice exporting countries, such as Vietnam and Thailand (FAO, 2003).

### 3.2. Global virtual water flows

As water productivity is generally lower in importing countries than in exporting countries, a given amount of food commodities is worth more virtual water in the former than in the latter. To illustrate this point visually, Fig. 3 depicts the net virtual water flows viewed from the exporting and importing sides in the 14 regions of the world.

The net volume of virtual water export is the net export quantities multiplied by the crop virtual water contents in the corresponding exporting countries. The net volume of virtual water import is the net import quantities multiplied by the crop virtual water contents in the corresponding importing countries. The two volumes represent the virtual water “values” of a given amount of food commodity measured at the source and destination. The data for the calculation are from the Commodity Trade Statistics Database (COMTRADE) of the United Nations Statistic Division in New York in collaboration with the International Trade Centre in Geneva (UN, 2003). Individual country’s virtual water export and import by source and destination is calculated first. All the countries are

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then grouped into 14 regions for a visual clarity.

North America, South America and Oceania are the net exporting regions of virtual water. All other regions are net importers. East Asia, Central America, North and West Africa and Middle East are the major destinations of virtual water. It can be seen that the volumes of virtual water differ largely on the exporting and importing sides. For example, the volume of  $73 \text{ km}^3$  of virtual water exported from North America is translated into  $149 \text{ km}^3$  of virtual water in East Asia. In the Middle East, the corresponding volumes are  $17 \text{ km}^3$  and  $55 \text{ km}^3$ , respectively. One exception is the virtual water export from South America to Western Europe. The virtual water exported from South America is worth less in Western Europe because water productivity in the former region is lower than the latter region.

Global food trade reduces the overall water use in world food production. This is of significance in terms of efficient use of global water resources. Down to the country level, such a saving is more important for the countries where water resources are scarce and water productivity is low. By importing food, these countries are able to benefit from both water resources and higher water productivity of exporting countries. For water abundant countries, however, the water saving in food import is less significant. Importing food is often not directly related to their water endowments. The significance of the global water saving should be viewed with these differences in perspective.

#### 4. “Green” vs. “blue” water in agricultural production and virtual water trade

In the hydrological cycle water resources can be divided into “blue” and “green”. Blue water refers to the water in rivers, lakes, reservoirs, ponds and aquifers (Rockström, 1999). Irrigated agriculture typically uses blue water. The concept of green water was first introduced by Falkenmark (1995) to refer to the return flow of water to the atmosphere as evapotranspiration ( $ET$ ) which includes a productive part as transpiration ( $T$ ) and a non-productive part as direct evaporation ( $E$ ) from the surfaces of soils, lakes, ponds, and from water intercepted by canopies. Later, green water has been generally

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used to refer to the water stored in the unsaturated soils (Savenije, 2000). Green water is the water source of rainfed agriculture.

Green water and blue water have different characteristics in many aspects. Table 3 summarized some features that are pertinent to agricultural production. Central to these differences are the opportunity costs and the hydrological/environmental impacts.

The opportunity cost of water is its value in other uses, such as in municipal, industrial, or recreational activities, and ecosystems. Green water comes from rainfall. Such water is a “free good” in terms of supply. Plants other than food crop (which often have lower direct economic value of water use) are the only major competitive users of this water. Hence, rainfed agriculture is rather efficient in terms of the opportunity cost of water use. Meanwhile, the environmental impact of the use of green water is relatively small because it generally does not change the distribution of water resources and the hydrological cycle.

In contrast, the opportunity cost of blue water in agriculture is high since it has many other functions. Irrigation often yields the lowest economic value among all the functions (Zehnder et al., 2003). Meanwhile, blue water requires facilities for storage and distribution before it can be delivered to users. The supply of water involves cost. The environmental impact of such water use is also significant as it changes the natural courses of water flows. Moreover, excessive irrigation can cause severe salinization, water logging and soil degradation, which are evident in many areas of the world. Taking into consideration the opportunity costs and environmental impacts in the use of water resources, trading green virtual water is overall more efficient than trading blue virtual water, holding other factors constant.

The ratio of irrigated areas to total crop areas indicates the dependence of a country's agricultural production on blue water. A high ratio means a high reliance on blue water. Both supply cost and opportunity cost of the water use is high. This is particularly so in water scarce countries where alternative uses of water often generate much higher returns. Conversely, a low irrigation ratio indicates a domination of rainfed

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agriculture. Such a practice is more efficient in terms of opportunity cost and supply cost.

The ratio of irrigated areas to total cultivated areas shown in Fig. 4 appears to have a high geographical correlation with the virtual water import/export depicted in Fig. 3.

5 In major food exporting countries, especially the USA, Canada, France, Australia and Argentina, the irrigation ratio is low. This situation indicates that food production in these countries is dominantly rainfed. A further inference is that food exporting countries generally export their green virtual water. In food importing countries, irrigation ratio varies widely but is on average higher than that in food exporting countries. This  
10 situation suggests that food importing countries have a higher dependence on blue water for agricultural production. This is not surprising given the close links between low precipitation, need for irrigation and the demand for virtual water import. For water scarce countries, using limited water resources for irrigation leads to allocation inefficiency. However, this inefficiency is often taken as a trade-off for easing other more  
15 pressing concerns, typically food security, rural employment and political stability. It is also noticed that in many poor countries, the irrigation ratio is low irrespective of their water resources. This situation is no doubt related to the lack of financial ability in these countries to bring water into irrigation.

## 5. Contribution of blue and green virtual water in global food trade

20 In order to specifically estimate the contribution of green and blue water in total virtual water trade, a virtual water partitioning is conducted below.

Let  $C$  be defined as the ratio of the yield on irrigated land to the yield on rainfed land:

$$\frac{Y_{irr}}{Y_{rf}} = C \quad (10)$$

For individual countries, total crop production can be expressed as:

$$25 \quad P_t = Y_{irr}A_{irr} + Y_{rf}A_{rf} = CY_{rf}A_{irr} + Y_{rf}A_{rf} = Y_{rf}(CA_{irr} + A_{rf}), \quad (11)$$

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where  $P_t$  is total crop production,  $Y$  is crop yield,  $A$  is crop sown area, and subscripts  $irr$  and  $rf$  denote, respectively, irrigated and rainfed items.

Crop production that is generated from green water on irrigated land and rainfed land can be calculated as:

$$P_{rf} = Y_{rf}(A_{irr} + A_{rf}) \quad (12)$$

Crop production that is generated from the supplement of blue water on irrigated land can be calculated as:

$$P_{bw} = P_t - P_{rf} = Y_{rf}(CA_{irr} + A_{rf} - A_{irr} - A_{rf}) = Y_{rf}A_{irr}(C - 1), \quad (13)$$

where  $P_{bw}$  refers to the production using blue water for irrigation.

As the average yield  $Y_{avg}$  can be expressed as:

$$Y_{avg} = \frac{Y_{irr}A_{irr} + Y_{rf}A_{rf}}{A_t} = \frac{CA_{irr} + A_{rf}}{\frac{A_t}{Y_{rf}}} \quad (14)$$

the yield on rainfed land can be calculated as:

$$Y_{rf} = \frac{A_t Y_{avg}}{CA_{irr} + A_{rf}} = \frac{P_t}{CA_{irr} + A_{rf}} \quad (15)$$

Replacing  $Y_{rf}$  in Eq. (13) with Eq. (15), the contribution of blue water can be specified as:

$$P_{bw} = \frac{P_t A_{irr}(C - 1)}{CA_{irr} + A_{rf}} \quad (16)$$

In order to estimate  $P_{bw}$  quantities  $C$ ,  $A_{irr}$  and  $A_{rf}$  for each country need to be defined. As  $C$  is not available for most of the countries, an average crop yield ratio of 1.5 suggested by the United States 1998 agricultural census (USDA, 2003) is used for all the net food exporting countries. The use of this ratio is reasonable because most

net food exporting countries are located in the temperate climate zones where irrigation is often supplementary rather than essential. Meanwhile, an average percentage of irrigated areas in individual countries is used for all the crops considered. In reality, the percentage of irrigated areas for cereal crops, except for rice, is usually lower than that for vegetables and fruits. Using the average percentage of irrigated areas in the partitioning tends to overestimate the contribution of blue water in the virtual water trade.

Figure 5 shows the result of the virtual water partitioning for the seven largest food exporting countries. These countries account for about 80% of the total virtual water export. It can be seen that the proportion of blue virtual water export in these countries is considerably low. In Canada, it is negligible. The result shows clearly that the global virtual water export is overwhelmingly “green”.

It should be pointed out that during the past four decades; irrigated areas for the world as a whole have nearly doubled. Most of the increase has taken place in food importing countries (FAO, 2003). Some food exporting countries, however, have also seen significant increases. As a result, overexploitation of water resources has occurred in many regions of the world, including those in the exporting countries. In the central and western United States, for example, many rivers and aquifers have been over-exploited causing serious regional water resources depletion and environmental degradation (Postel, 1996). Today, irrigated land accounts for about 17% of the total cropland of the world while producing over 40% of the total food (Rosegrant et al., 2002; Rijsberman, 2002). It is estimated that under the business-as-usual scenario, about 17% increase in irrigation water supply would be needed worldwide to meet the demand for food in the coming 25 years (Rijsberman, 2002). Although most of the increase would be in food importing countries, an expansion in irrigated areas in food exporting countries could also be expected as a result of the increasing demand for their virtual water. This could aggravate the regional resource depletion and environmental degradation in food exporting countries on the one hand and reduce the water use efficiency embodied in the global virtual water trade on the other.

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## 6. Concluding remarks and policy implications

This study investigated the efficiency gains embodied in the global virtual water trade. The perspectives of exporting and importing countries are specified. The characteristics of green and blue water and their contributions in the global virtual water trade are elaborated.

The examination shows that water productivity in food exporting countries is generally higher than that in food importing countries. A global water saving, therefore, results from food trade. The contribution from the trading of wheat and maize to the global water saving is particularly large.

Major food exporting countries overall have a low irrigation intensity. The proportion of food production from irrigated areas is considerably small. The global virtual water trade is dominated by green water. Such a trade is efficient in terms of opportunity costs of water use and environmental impacts.

Virtual water import has effectively reduced the water use for food production in the importing countries. For many of these countries, it is often cheaper and less ecologically destructive to import food, especially the water intensive cereal crops, than to transport water to produce the same commodity locally. This strategy is particularly efficient when the world prices of food commodities are lower than the cost of production in the food importing countries (Wichelns, 2001). Over the last 30 years, the world prices for major cereal crops have declined by about 50% (Rosegrant et al., 2002). Water deficit countries have been able to access the virtual water at the advantageous price. However, it has been projected that in the coming years the decline in food price will be at a slower rate (Rosegrant et al., 2002), posing disincentive to food import. For water rich exporting countries, exporting green water is in line with their comparative advantage in water endowments while the environmental impacts are relatively small.

Finally, it must be pointed out that the current global virtual water trade is primarily among the countries above the low-income level in the World Bank country classification. The efficiency gains from the global virtual water trade are attained mainly by



these countries. The low income countries have a much less participation in global virtual water trade. Among many reasons, the low income and consequently the low ability to exploit natural resources and invest in agriculture are largely responsible. The lack of financial resources also deprives these countries' choice of purchasing food from the international market when the domestic food supply is in shortage. Therefore, one should be cautious to expect miracles from the virtual water concept in addressing the food security problems in poor countries. From the viewpoint of efficient use of global water resources and considering the lack of financial ability in poor countries to develop irrigated agriculture, greater efforts, particularly agricultural technologies and investment, should be devoted to the development of rainfed agriculture. Given the increasing scarcity of global blue water resources, more effectively utilizing green water may have to be a direction to which the world agriculture will pursue in the future.

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**Table 1.** Major food crops included in the virtual water accounting.

Commodity groups	Specific commodities
Cereals	Wheat, rice, maize, barley, sorghum, millet, others
Starchy roots	Cassava, potatoes, sweet potatoes, other roots
Sugar crops and sugar	Sugar cane, sugar beat, sugar (raw equivalent)
Oil crops and oil	Soybeans, groundnuts, sunflower seeds, soybean oil, groundnut oil, sunflower seed oil

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**Table 2.** Global Virtual Water Import and Export and the Scale of Water Saving, average over \* 1997–2001.

Crops (km <sup>3</sup> year <sup>-1</sup> )	Global gross virtual water import (km <sup>3</sup> year <sup>-1</sup> )	Global gross virtual water export	Global water saving	
			Volume (km <sup>3</sup> year <sup>-1</sup> ) virtual water import	Ratio of virtual water saving to total
Wheat	318.8	188.4	130.3	40.9
Rice	53.5	63.2	–10.1	–18.8
Maize	97.3	39.5	57.4	59.0
Barley	55.1	31.7	20.1	36.4
Soybean	104.9	67.3	37.1	35.3
Others**	351.1	249.2	101.9	29.0
Total	980.7	644.0	336.8	34.3

\* An average of 15% sugar content is used to convert sugar (raw equivalent) to sugar crop weight equivalent. An average of 30% oil content is used to convert oil to oil crop weight equivalent.

\*\* Others refer to the rest of the crops listed in Table 1.

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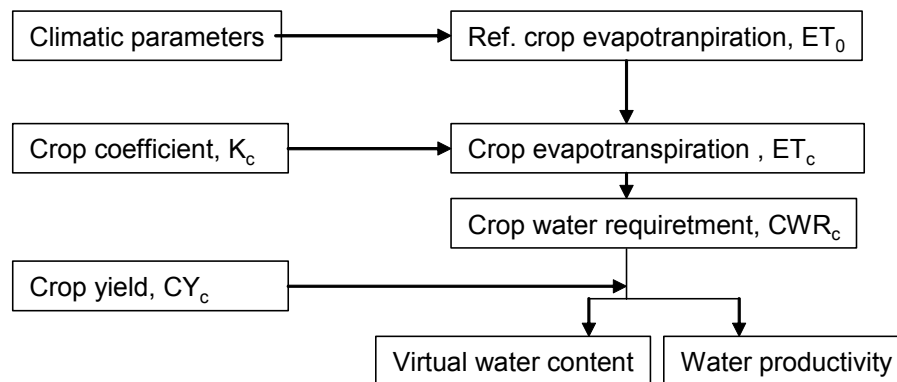
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**Table 3.** Characteristics of the blue and green water.

Type of water	Blue	Green
Sources	rivers, lakes, reservoirs, ponds, aquifers	water that is stored in the unsaturated soil and can be used for evapotranspiration
Mobility	highly mobile	highly immobile
Substitution of sources	Possible	impossible
Competitive uses	Many	few
Conveyance facilities	Required	not required
Cost of use	High	low
Impact on hydrological system	Significant	less significant
Adverse effects on soil	significant (e.g. salinization and water logging)	less significant



**Fig. 1.** Steps of the estimation of virtual water contents.

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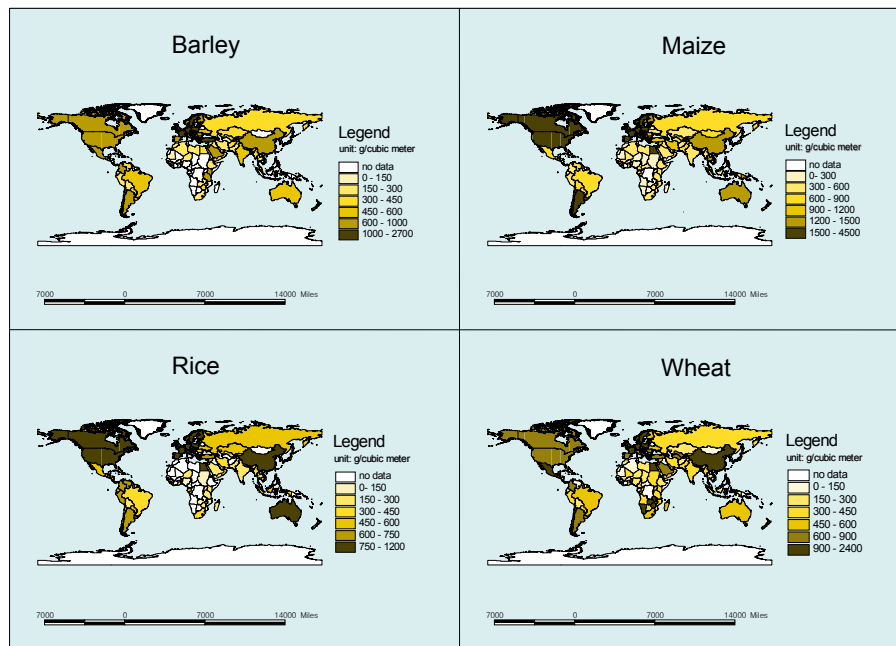
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**Fig. 2.** Water productivity of major food crops by country, average over 1997–2001.

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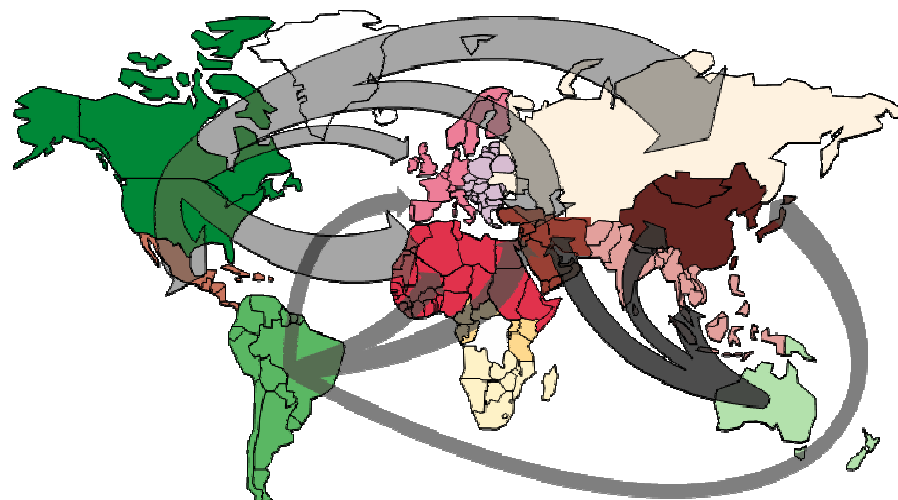
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Exporter	VW km <sup>3</sup>	Importer	VW km <sup>3</sup>	Exporter	VW km <sup>3</sup>	Importer	VW km <sup>3</sup>	Exporter	VW km <sup>3</sup>	Importer	VW km <sup>3</sup>
N-America	73	E-Asia	149	S-America	30	W-Europe	26	Oceania	15	E-Asia	20
	30	C-America	64		21	E-Asia	25		11	S+E-Asia	24
	22	N+W-Africa	58		18	M-East	35		10	M-East	14
	17	M-East	55		12	N+W-Africa	21		13	Others	24
	12	W-Europe	17		15	Others	38				
	27	Others	71								

**Fig. 3.** Virtual water flows by regions, average over 1997–2001.

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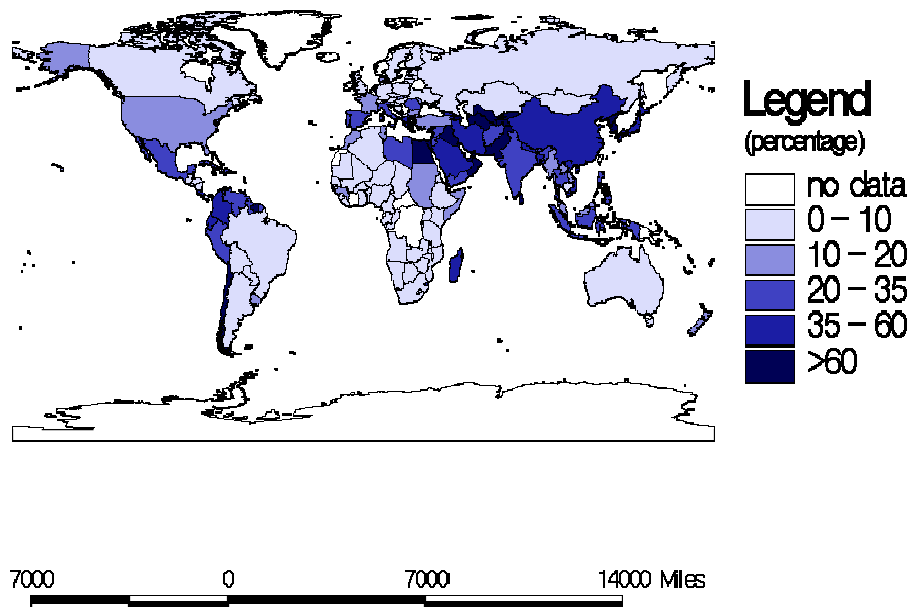
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**Fig. 4.** Ratio of irrigated areas to total cultivated areas, average over 1997–2001.

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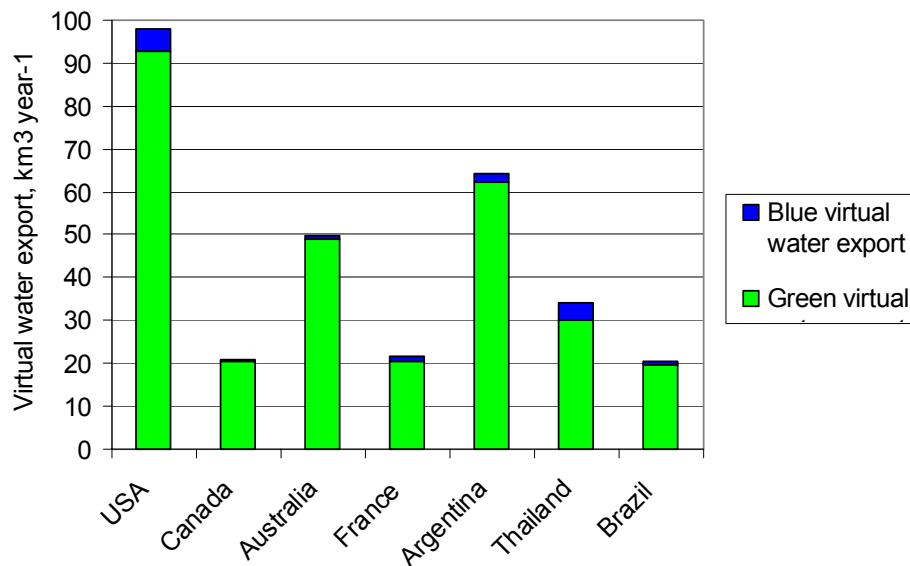
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**Fig. 5.** Blue and green virtual water in major exporting countries, average over 1997–2001.

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